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Introduction:

The Maine Department of Environmental Protection (MDEP) stormwater regulations in the past have focused on flood control and peak flow attenuation. Many older Best Management Practices (BMPs) in the Penjajawoc Watershed perform according to these standards. More recently, focus shifted to water quality aspects and some recent BMPs were equipped to improve upon pollutant loading conditions (80% total suspended solids (TSS) removal). In November 2005, the MDEP concluded that the past methods were not performing in the desired manner. Studies found that the 1- or 2-year frequency events generally made the channel unstable, and that infrequent high flow events were not as damaging as once thought. As a result, the stormwater regulations were revised. Implementation is under way; however, few BMPs in the Penjajawoc Watershed are compliant with new Low Impact Development (LID) BMP standards.

MDEP contracted WBRC Architects-Engineers to perform a hydrologic analysis of the Penjajawoc Watershed and to propose four (4) new or retrofit LID storm water BMPs to improve the water quality of the stream during a baseline flow condition (up to 2-year storm) and to target hydrologic and pollutant goals listed in the TMDL. It should be noted that the Total Maximum Daily Load (TMDL) report for Penjajawoc Stream is not yet available.

Two (2) other firms were contracted to do parallel studies on the Penjajawoc Watershed. ENSR Corporation and Parish Geomorphics, Ltd. were retained to perform a SWMM model and geomorphologic analysis, respectively. Results of these studies were used in this report to augment base flow data in order to enable WBRC to provide a target 2-year hydrologic analysis. It should be noted that while WBRC was contracted to study only runoff directly entering the Penjajawoc Stream, both ENSR Corporation and Parish Geomorphics, Ltd. compiled data for two adjacent subwatersheds. In addition, a recent P-8 program report (Tetra Tech, 2003) was reviewed to support watershed ground cover and imperviousness values used in the Hydrocad model.

The purpose of this study was as follows:

1. Identify and calibrate target watersheds hydrology for critical storm flow using Hydrocad in conjunction with data obtained from recent SWMM modeling and geomorphic analysis. Use of archived hydrology data where possible to create the watershed model.
2. Review stream geomorphology results and SWMM model results to determine critical issues.
 - *Thermal*
 - *Pollutant Loading*
 - *Hydrology*
 - *Dissolved Oxygen*
4. Inventory existing BMPs and identify (4) BMP sites for implementation/remediation.
5. Prepare a report for use by watershed managers and stakeholders to use as a guide for future development.

1.0 – General Findings & Background

1.1 – Watershed Characteristics:

The Penjajawoc Stream Watershed is a 5,600-acre watershed located to the northeast of Bangor, Maine in Penobscot County. The Penjajawoc Stream is 27,000 feet (5.2 miles) long and contains 10 tributaries, among which are Meadow Brook and Tributary #3 (Mt. Hope Cemetery). The upper watershed contains a large 300-acre emergent freshwater marsh known as Penjajawoc Marsh. This marsh is bisected by the now obsolete Veazie Railroad bed. (Figure 1.0) See also figure A-1 Site Location Map in Appendix A.

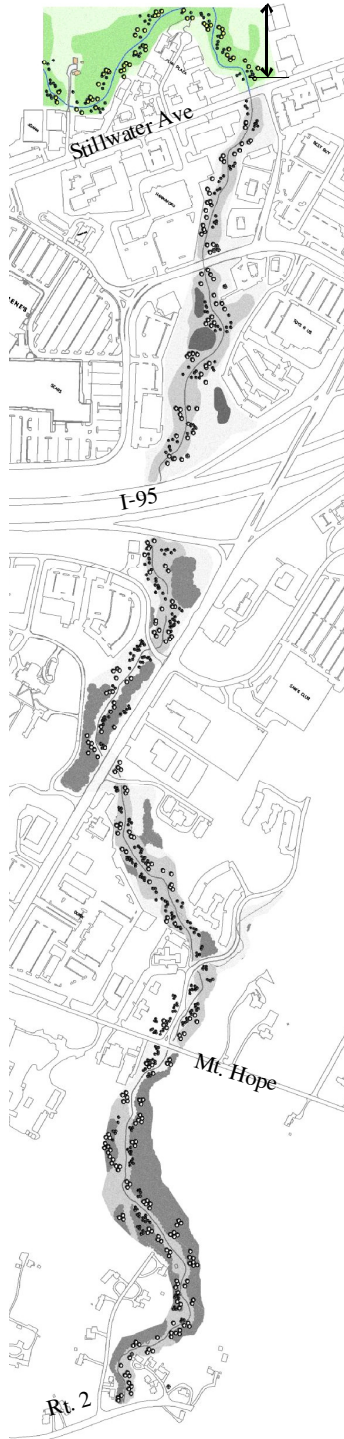


Figure 1.1 Upper Reaches

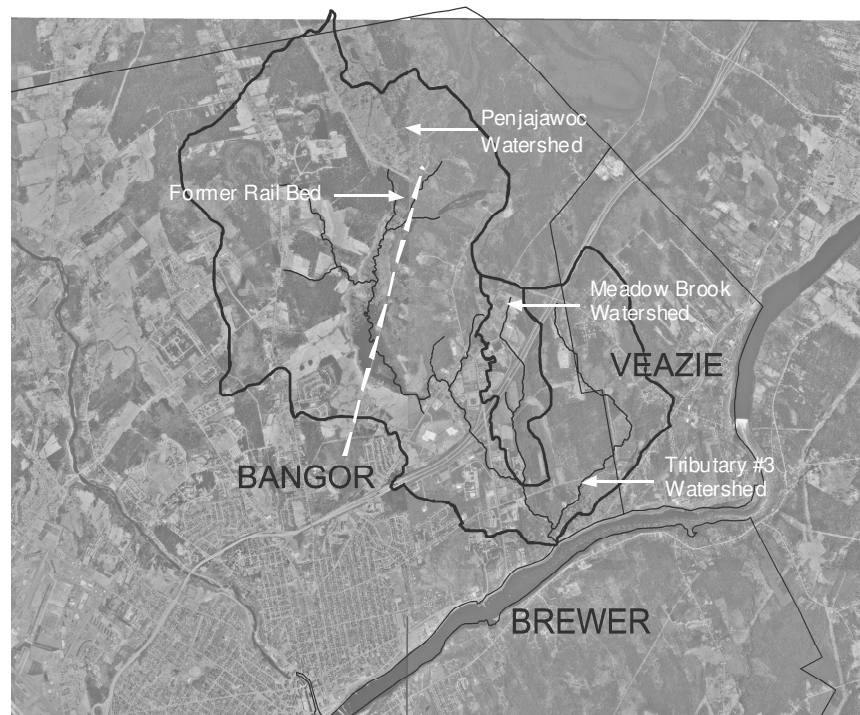


Figure 1.0 Watershed Location (USGS 1995 photo base)

The mouth of the stream is at elevation 1.81 feet NGVD.¹ The stream has a gentle slope with no reaches being steeper than 1% average slope. The highest point in the entire watershed is at elevation 300. See figure A-2 Stream Reach Identification in Appendix A for topographic reference material.

¹ The National Geodetic Vertical Datum of 1929 was used throughout this project.



Figure 1.2 Middle Reaches

The Penjajawoc Watershed has been impacted by development in the past 30 years. The developed areas are expected to see continued growth, adding to the impervious coverage. The upper watershed is largely undeveloped and forested.

1.2 – Headwater Characteristics:

Penjajawoc Marsh lies to the north of the site and serves as a headwater to the stream. The marsh attenuates runoff from the upper watershed. It is part of a large system of bogs named for nearby Caribou Bog, which formed because of the flat elevation and poorly drained soil types of the surrounding area. Much of the acreage of Penjajawoc Marsh is owned by the City of Bangor.² It should be noted that Penjajawoc Marsh is an area of conservation interest because it serves as a refuge for migratory waterfowl.

1.3 – Stream Characteristics:

The Penjajawoc Stream is classified as a Class B water body under the Maine Water Quality Standards classification of fresh surface waters and designated uses. For the purpose of this study, the upper reach includes the 3,463-acre tributary above the Stillwater Avenue road crossing (sta. 10+111), and its land coverage includes the aforementioned 300-acre Penjajawoc Marsh. (Figure 1.1) The middle reaches of the stream flow through a developed urban area, causing this stream to be 303(d) listed for statutory impairments to aquatic life due to non-point sources.³ (Figure 1.2)

The Penjajawoc Stream flows directly into the Penobscot River, which behaves as mild tidewater at the stream exit site. (Figure 1.3) The Penobscot River continues into the Gulf of Maine. The mouth of the Penjajawoc Stream contains an alluvial delta. Aerial photography suggests that this deposit has indeed come from the Penjajawoc; additional inspection during June of 2006 led to the tentative conclusion that the delta has been present for many years, but shifts position periodically.

As shown on the Flood Insurance Rate Maps (FIRM, included in Appendix A), many places in the watershed are

² Maine Natural Areas Program

³ Maine Water Quality Standards, 1998 303(d) list



Figure 1.3 Lower Reaches

susceptible to flooding. There is beaver activity throughout the watershed that also contributes to localized flooding. (Figure 1.4)

The stream channel is estimated to have changed several times over the years, both from natural processes and from human activity. The developed area was formerly a dairy farm and some segments may have been flattened and straightened to accommodate the farming needs. More recently, development has encroached upon the banks, causing similar changes. Stream crossings were installed where needed. Several tributaries have been diverted through culverts and a segment of the Penjawoc appears to have been filled to accommodate a parking lot.

1.4 – Highlights of Parallel Studies:

- **Parish Geomorphic, Ltd.:**

During July of 2005 to November of 2005, Parish Geomorphic, Ltd. conducted a geomorphologic study of the stream channel, which consisted of an existing conditions inventory, erosion pin and cross section monitoring, interpretation, and recommendations.

Fluvial geomorphology is defined as “the study of...landform development as influenced by moving water such as rivers and streams.”⁴ Before conducting the current evaluation, Parish conducted a preliminary report in 2003. This report concluded that the stream channel had been adjusting to accommodate the effects of land use change. These changes were both directly fabricated and gradual channel alterations. The report recommended additional monitoring and suggested preliminary stream restoration practices such as bank erosion control and effective stormwater management.

The 2006 report entailed analysis of stream adjustment at six cross sections, three of which were in the Penjawoc channel (the others being in tributaries). The report measured the change in cross sectional area and attempted to accurately portray stream bankfull conditions and critical conditions. Parish defines “bankfull” conditions as the level of flow, corresponding to approximately the 1.5- to 2-year storm event, at which the flow fills the stream channel but

⁴ Endreny



Figure 1.4 Present or former beaver activity

does not spill into the flood plain. Stream “critical” conditions are defined as the discharge where the average-size particle begins to move, and hence the stream begins to erode.

Parish divided the stream main channel into 13 reaches, which are shown in the following table according to the station at which they start. For reference, refer to figure A-2 in Appendix A.

TABLE 1.0 – PARISH REACH LOCATIONS

PARISH REACH	STARTING STATION
PS-1	0+000
PS-2	0+950
PS-3	3+700
PS-4	5+400
PS-5	7+250
PS-6	8+900
PS-7	10+000
PS-8	12+500
PS-9	13+700
PS-10	15+650
PS-11	20+100
PS-12	23+100
PS-13	24+300
End	27+255

In addition to monitoring stream cross-sections, erosion pins were used to evaluate rates of channel adjustment. The pins demonstrated a low level of channel change but additional monitoring was recommended. The results led to the conclusion that, while the stream is currently undergoing slow transition, stream features suggest past disturbances. It was concluded that the stream was behaving as an urban system.

Parish observed that the upper and middle reaches of the stream channel are wide and shallow, causing the stream to move slowly and to lose sediment. As a result, stream aggradation is occurring. Aggradation is the process by which a stream deposits sediment. This condition was reversed in the lower reaches, as degradation occurred because of a narrower stream channel, steeper channel slopes, and increasing flow rates. Degradation is simply the opposite of aggradation, in which the stream erodes sediment. Parish recommended detailed stream bank restoration techniques for specific reaches in the stream and its

tributaries. Additional monitoring was also recommended to obtain a long-term estimate of trends.

The Penjajawoc Stream was found to have issues of channel migration, bank erosion, and sediment accumulation. The critical issue outlined in the geomorphic analysis was the fact that erosion and deposition trends need to be addressed; otherwise, water quality, aquatic habitat, and infrastructure may become threatened.

- **ENSR Corporation:**

ENSR Corporation conducted a Storm Water Management Model (SWMM) using similar watershed parameters as WBRC, which are described in supplemental information in Appendix B. The SWMM model analyzes the buildup, washoff, and treatment of typical stormwater pollutants and predicts average runoff and stream flow on an annual basis. Among the modeling assumptions by ENSR were constant hydrologic soil group “C”, uniform trapezoidal stream channel geometry, pervious and impervious land use types, and statistically average rainfall conditions. Buildup-washoff and removal/treatment expressions were derived for seven (7) pollutant parameters:

- total suspended solids (TSS);
- phosphorus (P);
- total Kjeldahl nitrogen (TKN);
- zinc (Zn);
- copper (Cu);
- lead (Pb);
- petroleum hydrocarbons (HC).

Similar parameters were used by Tetra Tech, Inc. in a P8 Model prepared for Penjajawoc Stream in 2003. Results represent average conditions over an annual period.

Results were compiled for four points of interest on the stream:

- 0+000 – Confluence with Penobscot River (mouth of stream);
- 3+740 – At the confluence of Meadow Brook;
- 7+220 – At I-95 culvert, downstream of Bangor Mall;

- 10+080 – Downstream of headwater wetland (Stillwater Ave. crossing).

ENSR concluded the SWMM report with an expression of total annual pollutant loads under existing conditions. See figure A-2 in Appendix A for locations of stations.

TABLE 1.1 – SWMM RESULTS

POLLUTANT	ANNUAL LOAD (LBS)			
	10+080	7+220	3+740	0+000
TSS	370.00	990.00	1,500.00	1,590.00
P	2.60	5.40	8.20	8.80
TKN	13.00	27.00	41.00	44.00
Cu	0.31	0.62	0.93	1.00
Pb	0.10	0.23	0.35	0.38
Zn	1.40	2.90	4.40	4.70
HC	12.00	29.00	44.00	47.00

The SWMM model did not attempt to diagnose any critical issues; instead, ENSR intended the model to be used to compare existing conditions with potential improvements in the future. The model would have to be updated as additions or deletions to existing BMPs took place. The results were to be used for comparison of potential scenarios in addition to actual future conditions.

1.5 – Groundwater Depth:

To aid in the prediction of maximum and minimum expected groundwater flows as visible in stream baseflow, or exiting from underdrained storm systems, data from a USGS groundwater monitoring station in Kenduskeag was reviewed. The following table highlights the wettest and driest part of the seasonal groundwater, noted as the lowest and highest values, respectively. As an example, underdrain flow observed exiting the Bangor Mall drainage system during late August is measured to be at its lowest flow rate. Additional monitoring should be conducted in April of the following season.

TABLE X.X DEPTH TO GROUNDWATER (FEET)

Average		Minimum		Maximum	
Month	Total	Month	Total	Month	Total
Jan	21.91	Jan	16.84	Jan	26.98
Feb	21.99	Feb	17.08	Feb	26.70
Mar	20.89	Mar	15.09	Mar	25.02
Apr	18.77	Apr	14.92	Apr	22.89
May	19.83	May	16.13	May	22.29
Jun	21.36	Jun	16.58	Jun	23.45
Jul	22.75	Jul	18.79	Jul	24.63
Aug	23.74	Aug	20.43	Aug	25.45
Sep	24.53	Sep	20.96	Sep	26.91
Oct	24.31	Oct	17.85	Oct	26.58
Nov	23.13	Nov	17.48	Nov	27.08
Dec	21.96	Dec	15.76	Dec	27.32
Average	22.08	Average	17.33	Average	25.44

2.0 – Hydrologic Model

2.1 – Methods and Assumptions:

A hydrology model using the Hydrocad v. 7.10 computer model was developed using TR-20 and TR-55 methodologies. This model was chosen due to the ability to input existing (Hydrocad) record data, the need to permit future developments to access and modify the model, to determine the appropriate timing of discharge, and to guide BMP selection. Approximately 275 record drawings were scanned for use in developing a current representation of the watershed characteristics. See table A-1 in Appendix A listing the record documents used in this report.

With the exception of three contributing subareas, time of concentration (T_c), coverage (CN), and time of travel (T_t) were developed to build and calibrate the model to match observations. Due to the complexities of the headwater tributary (above Stillwater Avenue), and the natural attenuation of the Penjajawoc Marsh, wooded areas, and organic layers within, a stream base flow was assigned based on the Parish Geomorphic observation in lieu of a standard hydrograph. Since the timing of the runoff from the wooded areas and marsh lag the peak period of the lower developed watersheds, this approach appeared to calibrate best with observed conditions for the 1- and 2-year storm events. Although outside the scope of this study, runoff from Meadow Brook and the Tributary #3 were similarly assigned a base flow value to permit calibration of the stream model with other published results (FIRM) at the confluence with the Penobscot River.

Since prior hydrologic models for new development were typically developed on a subarea-by-subarea basis, they rarely analyzed the cumulative effect of BMP development to overall stream peak flow timing or intensity. Tabular results of this analysis are contained in section 2.3.

Hydrocad offers three routing methods for its hydrologic modeling system: the “storage-indication” method, the “dynamic-storage-indication” method, and the simultaneous routing method. The storage-indication method is a sequential procedure in which each node (reach or pond) is calculated one-at-a-time in a fixed order. This technique, while being fast and widely accepted, does not allow for tailwater conditions. In the dynamic-storage-indication method, the nodes are also calculated in a sequential order. However, in this method, each node is re-evaluated at each time step, allowing upstream nodes to respond to changing tailwater conditions. The simultaneous method is used when a flow order is not necessary or not known. This method is intended for use only with certain special conditions, such as tidewater effects.

For this analysis, the “dynamic-storage-indication” method was selected to observe the effects of tailwater on subarea runoff and to model step-backwater conditions with minimal flow oscillation.

In this study, the impact to stream peak flow of each BMP retrofit was analyzed in the model to optimize 1- and 2-year discharge rates, and to monitor unintentional downstream flooding and peak flow rates for 10-, 25-, and 100-year storm events.

Since the base flows assigned for the headwater and tributaries were representative of observed conditions at the time of this study, it is recommended that stream flow gauging be conducted on a regular basis to provide accurate base flow data for the hydrologic model. As LIDs are developed to mimic natural stream base flow, stream capacity to handle stormwater events within the 2-year bankfull/critical depth will decrease, affecting decisions for implementing future BMP selection.

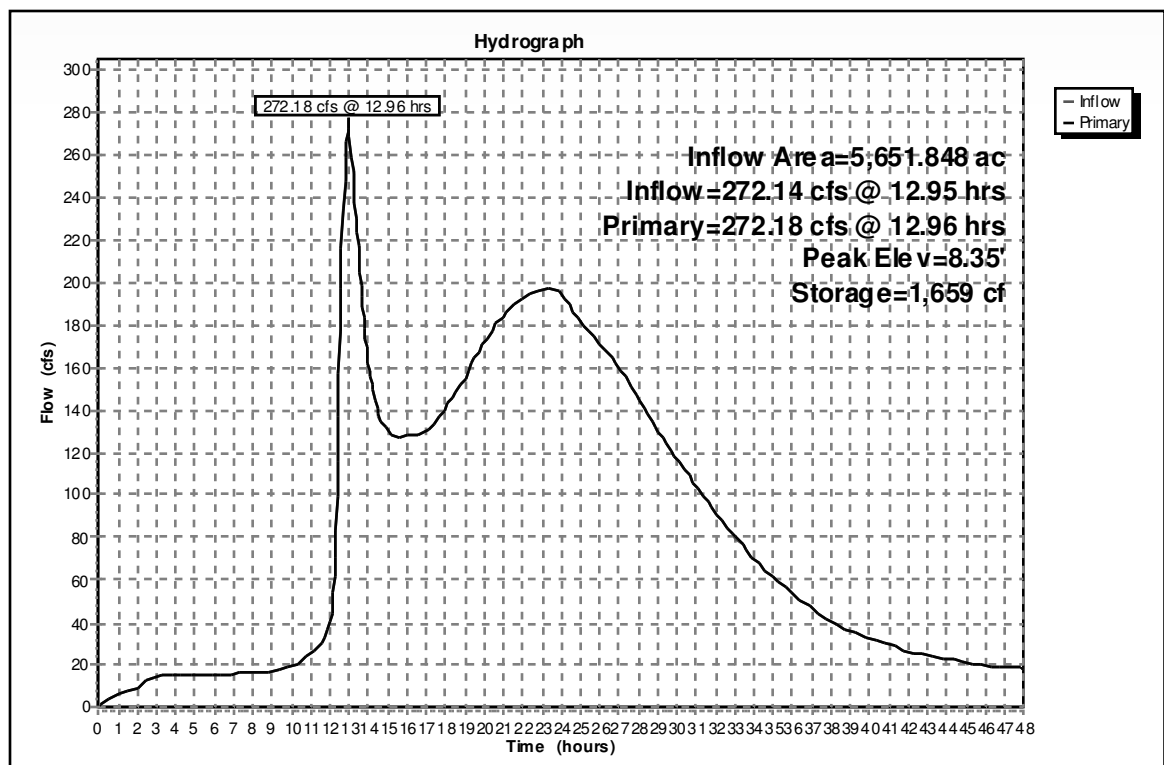
Retrofit of a typical wet/dry detention basin outlet to control a 1-year event vs. a 2-year event will alter its stage/storage curve, resulting in a system that could begin to reach its capacity prior to the original 25-year design event. It is therefore important that all BMP pond retrofits affecting stormwater storage be modeled within this program set to prevent unintentional downstream flooding and erosion. We strongly encourage the creation of a watershed coordinator position. This individual should be responsible for ensuring that the hydrologic model is properly updated for any development occurring within the Penjajawoc Watershed.

2.2 – Limitations of the Hydrologic Model

1. The impact of beaver dam activity was discussed jointly with MDEP and the consultant teams. It was decided that this phenomenon was unpredictable, and if necessary, could be corrected to restore the stream to the anticipated target condition. The model did not identify these structures within stream reaches.
2. Dt was adjusted to 0.05 hours to remove any latent oscillations within the hydrograph output.
3. Calibration of the model consisted of visual observations of bank-full erosion depths, scour line indicators on culverts and below road crossings, and comparison to other published data (FIRM).
4. The 36' span bridge serving Bangor Federal Credit Union was omitted from the model due to the fact that a prior HEC-2 analysis of the structure determined that the flooding impact to the 32' wide floodway in a 100-year event would be less than 0.2'. As such, there was no appreciable ponding or attenuation of stream flow at this structure during 1- and 2-year events.
5. Stage-storage relationships were determined using city digital and record drawing topography at road crossings. A field survey of impounded areas was not conducted.
6. Field data collected for road crossings was limited to inlet invert, outlet invert, size, condition, type, length, and observed tailwater depth during June of 2006. Scour lines were photographically documented with a vertical scale reference.

7. Use of the “upland” method outlined in NEH-4 to determine the approximate time of concentration (T_c) of the headwater (above Stillwater Avenue) gave a watershed lag time of 5 hours. Estimates of lag times using Hydrocad gave lag times of 9.85 hours for the upper watershed, 7 hours for Tributary #3, and 2.7 hours for Meadow Brook. The total lag time was found to be roughly 10 hours. (See **table 2.0** below.) It was determined that these tributary outflows could be omitted to permit focus on developed watershed peak runoff since peak flow amounts will not be interfering with one another. Record documents have also indicated that this is the case; inspection of SLODA from past projects in the developed area found that other firms had made a similar assumption.

**TABLE 2.0 WATERSHED PEAK FLOW WITH OUT-OF-SCOPE TRIBUTARIES
(1-YEAR STORM; ASSUMED T_c , CN)**



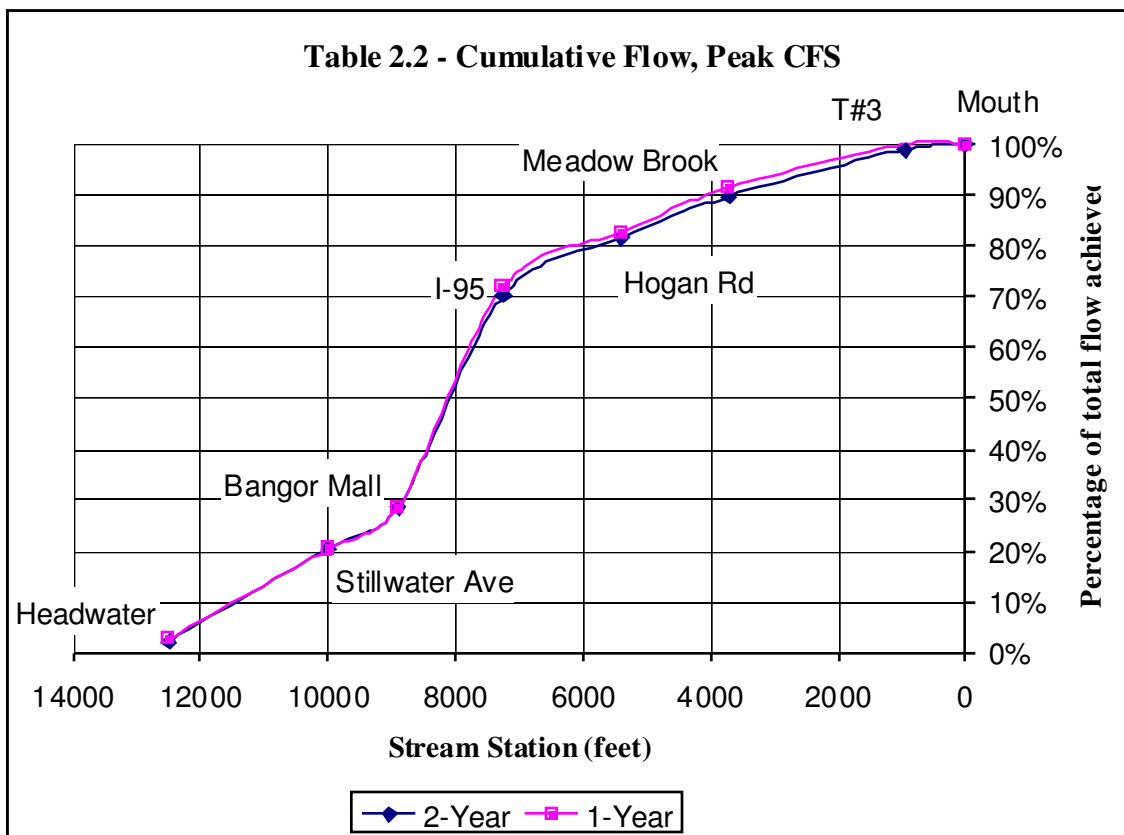
The first peak represents the peak outflow from the developed middle reach section. The second, broader peak represents the attenuated inflow from the wooded tributaries. The overall first peak flow increased by a mere 2 cubic feet per second (cfs) with the addition of the estimated tributary flows. The value shown in this graph should not be taken as exact. Stream flows from these out-of-scope tributaries should be gauged to verify the assumptions in this and other reports.

2.3 – Results of Hydrologic Model:

The Hydrocad model prepared by WBRC predicted the following peak flow rates for the stream for existing conditions.

TABLE 2.1 – FLOW AMOUNTS AT STATIONS (EXISTING CONDITIONS)

STATION	PEAK FLOW (1-YEAR, CFS)	PEAK FLOW (2-YEAR, CFS)	DESCRIPTION
0+000	270.44	324.78	Mouth of Stream
0+950	270.56	321.46	Tributary #3 confluence.
3+700	247.29	291.64	Meadow Brook confluence
5+400	223.77	265.17	Hogan Road crossing
7+250	194.52	228.02	I-95 crossing
8+900	77.23	92.87	Bangor Mall Blvd crossing
10+000	54.84	66.43	Stillwater Ave crossing
12+500	7.00 ⁵	7.00 ⁵	Headwater (assigned)



The table and graph above illustrate the significant (40%) contribution in peak flow from the developed area between Bangor Mall Boulevard and Interstate 95.

⁵ Since the observed base flow represents a steady-state condition, it retained its value for 1- and 2-year storms.

2.4 – Relationship to Imperviousness:

Stream condition has generally been shown to directly relate to a variable known as “imperviousness”, defined as all roads, parking lots, sidewalks, roofs, and any other areas that are not “green”.⁶ Generally, stream degradation occurs at or near a level of 10% total watershed imperviousness. The Penjajawoc Watershed currently has a watershed imperviousness of 8%.⁷

An impervious area generally contributes runoff in greater amounts than does a pervious one. It was found that subareas with high ratios of runoff to acreage were areas that had a high percentage of impervious coverage and insufficient BMPs. Areas with effective BMPs and/or natural coverage conditions had lower ratios. See Appendix B for Hydrocad routing diagram and figure A-3 Subwatershed Identification in Appendix A. See also figure A-2 for stream station identification.

⁶ Schueler & Holland

⁷ Parish Geomorphic

**TABLE 2.3 – SUBAREA OUTFLOW PER ACRE, 2-YEAR STORM EVENT
(EXISTING CONDITIONS)**

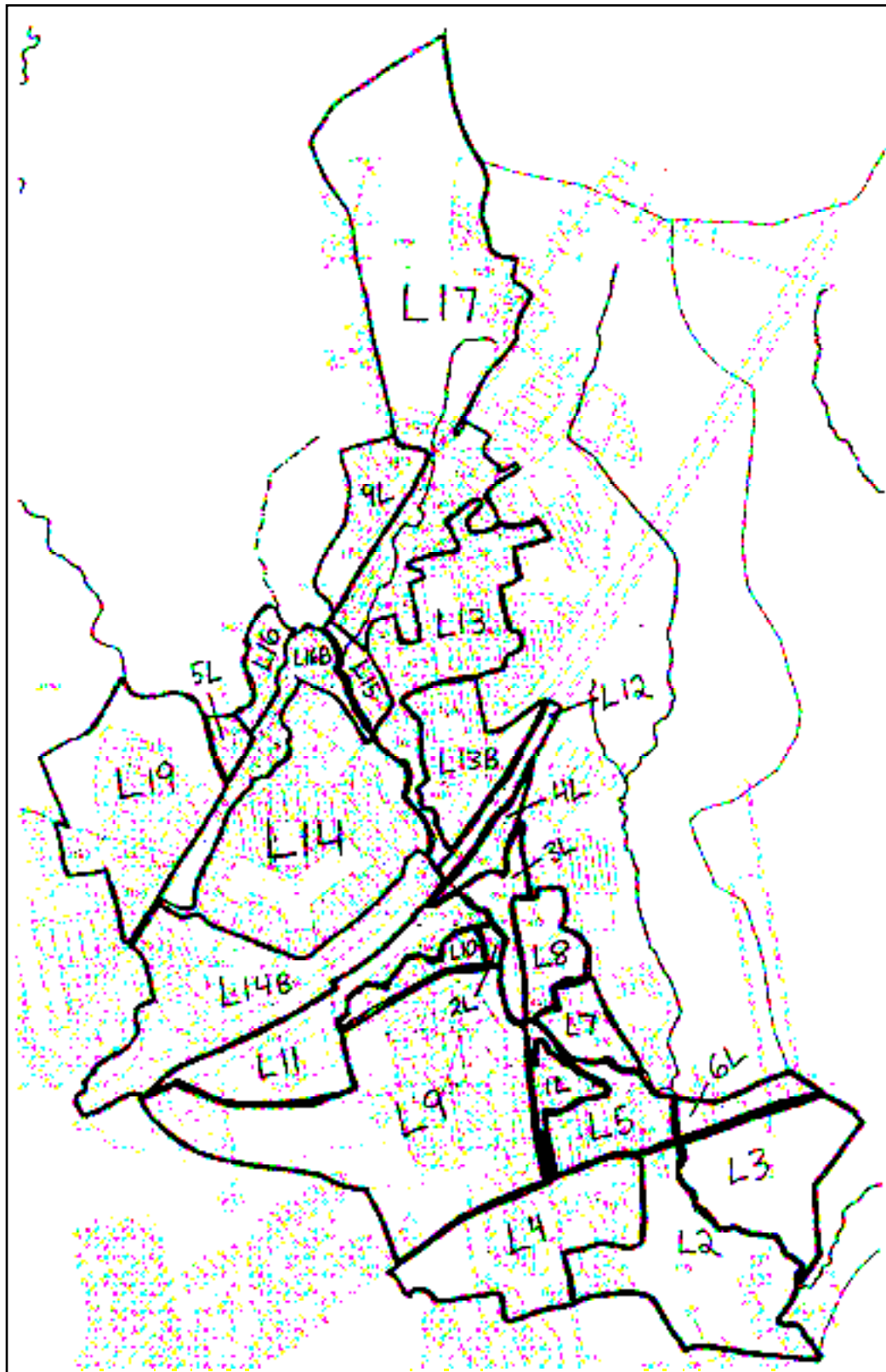
Stream Station	Link ⁸ Number	Description	Inflow Area (acres)	Outflow Peak (cfs)	Percent impervious ⁹	Peak CFS per acre	Subareas included in link
1+969	L2	WS100	49.92	8.03	12%	0.161	100
2+369	L3	WS 10	38.22	9.25	1%	0.242	10
3+165	L4	WS 110	43.62	20.50	40%	0.470	110, 520
3+165	6L	WS 11	8.36	3.64	13%	0.435	11
3+838	L5	Quirk Auto Park	21.48	20.94	53%	0.975	310, 300
4+809	1L	North Quirk	6.25	13.07	86%	2.092	322, 320, 311, 321
4+809	L7	BFCU	10.23	7.09	27%	0.693	200
5+246	L8	Dealerships	13.67	22.74	65%	1.664	412, 410, 411
5+400	L9	EMCC	115.03	17.07	20%	0.148	500
6+222	2L	Sylvan Rd	1.50	1.86	12%	1.242	1300
6+222	L10	Darling's Honda	10.18	12.14	84%	1.192	500
6+566	3L	Hogan Road	8.69	10.78	29%	1.240	400
6+566	L11	Sylvan Rd	35.31	14.85	27%	0.421	1700, 1500, 1710, 1711, 1712
7+005	4L	WS 600&1900	6.28	6.62	32%	1.053	600, 1900
7+420	L12	I-95	6.50	3.78	31%	0.582	800
7+420	L14B	Cinema/I-95, 2500 series	60.46	31.82	31%	0.526	2100, 2300, 2514, 2510, 2512, 2513, 2511
7+420	L13B	Lower 1000	25.54	8.89	51%	0.348	1010, 1030, 1040
8+188	L13	Upper 1000, K-Mart	42.47	83.15	66%	1.958	1000, 1220, 1090, 1091, 1092, 1093, 1094
8+188	L14	Bangor Mall 2550	75.37	53.08	41%	0.704	2550, 2500
8+919	L15	1200	6.52	10.57	47%	1.622	1200, 1210
9+832	L17	1200 series + Target	128.44	40.48	20%	0.315	1240, 1270, 1230, 1280, 1290, 1291, 1297, 1298, 1292, 1299, 1420, 1296, 1293, 1294
10+111	L16B	WS 2900	18.18	20.35	38%	1.119	2910, 2710, 2700, 2720, 2730, 2740, 2750
10+111	9L	1400 series	18.08	16.48	38%	0.912	1410B, 1410, 1412, 1413
10+888	L16	2900	7.97	9.22	45%	1.156	2900
12+121	5L	Joann	4.52	8.01	49%	1.773	2920
12+121	L19	WS 3100	56.07	38.94	47%	0.695	3110, 3160, 3150, 3140, 3130, 3120

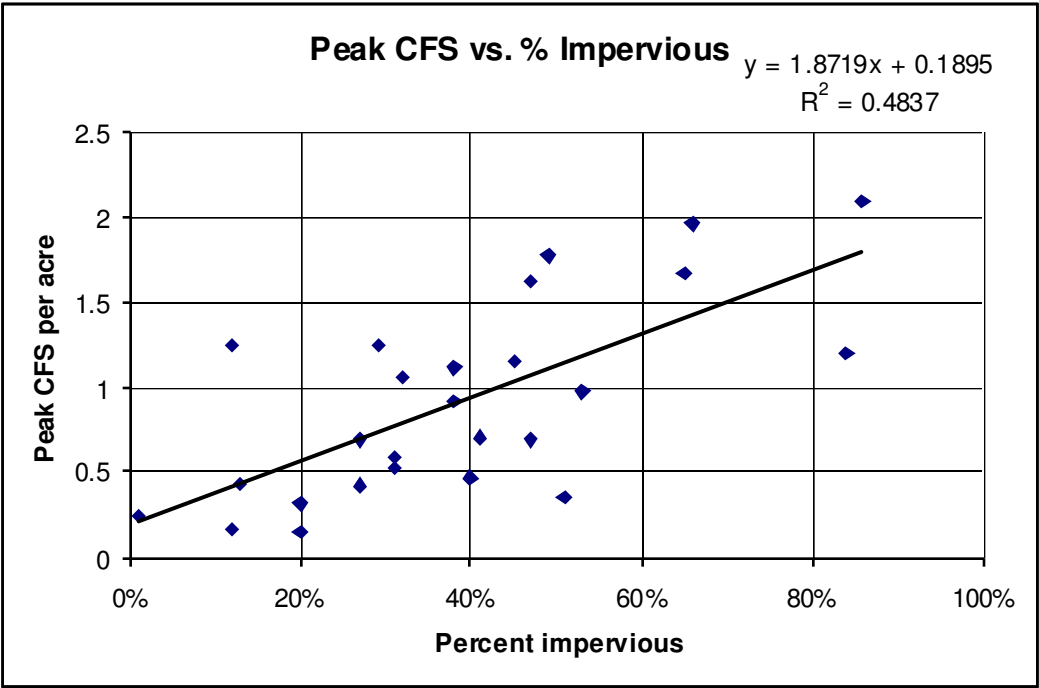
As expected, the peak runoff expressed in a “peak-per-acre” comparison is highest in subareas with higher imperviousness and without retention BMPs. This is important when reviewing BMP selection since, in some subareas, detention may still provide more benefit to the stream quality through peak flow reduction than other methods of runoff control, at or below a 2-year design discharge.

⁸ A “link” is an element within Hydrocad that signifies an entry point into the hydrologic model. In this case, a link represents a summary discharge for a group of subareas into the stream model.

⁹ “Percent Impervious” was calculated by analyzing the ratios of buildings and pavement to grassed areas within the defined tributary area. It does not reflect the percent coverage for any given parcel within.

FIGURE 2.0 LINKED DRAINAGE AREAS





2.5 – Existing BMPs:

Approximately twenty-five (25) existing retention Best Management Practices were observed and included in the hydrologic models to determine their effect on peak flow contribution. As these BMPs were built before a November 2005 update in Chapter 500 stormwater regulations, most do not comply with current quality standards.¹⁰ Methods of existing stormwater management observed include detention ponds, level spreaders, bioretention areas, and prefabricated products. (Table 2.4)

TABLE 2.4 – BMPS OBSERVED IN WATERSHED AFFECTING PEAK FLOW RATE

BMP #	W.S. #	Comment	Approx. Year Installed
1	5151	Target-Home Depot pond	1997
2	1292	Target level spreader	2004
3	1292	Ski Rack pond	1992
4	3120	Pond Avenue	not yet?
5	3120	3x Stormtreat	not yet?
6	3110	Pond Widewaters	not yet
7	3110	Bioretention areas (multiple)	not yet
8	2511	Cinema pond	1990
9	310	Quirk large pond	1998
10	320	Quirk small pond	2001
11	500	Pond EMCC ¹⁰	2006
12	1410	Crossroads pond south	1994
13	1412	Crossroads pond north	1994
14	1420	Retail pond	2001
15	1294	Ridgewood pond	1995
16	2550	Mall pond	1998
17	1091	Van Syckle pond	2001
18	1030	Toys R Us pond	1977
19	500	2x ponds Darling's	2004, 1987
20	200	Level spreader BFCU	1993
	OMITTED:		REASON:
	Crossroads uppermost pond		No development inflow
	Petco Stormtreat systems		Q _{in} =Q _{out}
	Second BFCU level spreader		Affected T _c , short distance
	Detention pond in WS 1280		Q _{in} =Q _{out}

¹⁰ One exception is found within BMPs created to address an 80% TSS reduction, which have been found to readily lend themselves to retrofit to the new treatment volume requirements without losing their value to control 2-, 10-, and 25-year peak events.

3.0 – Summary of Recommendations:

Due to the relatively sensitive nature of the Hydrocad hydrology model to certain BMP modifications or additions, it is important that all BMP pond retrofits affecting stormwater discharge into the stream be updated within this model. We strongly encourage the creation of a watershed coordinator position. This individual or firm should be responsible for ensuring that the hydrologic model is properly updated for any development occurring within the Penjajawoc Watershed.

Due to the complexities of land coverage, marsh storage effects, beaver dam activity, and large wooded areas, the upper Penjajawoc watershed, Meadow Brook tributary and Tributary #3, were not modeled as Hydrocad subareas, and were instead each input as an assigned 2-year base flow value. These values were obtained from the companion reports, which are not based on actual logged stream flow values. It is recommended that stream flow gauging be conducted on a regular basis at the three points identified above to provide accurate base flow data for the hydrologic model.

As a result of the hydrologic model's predictions for 1- and 2-year storm events and the observations within the SWMM and geomorphic analysis, four BMPs were identified:

1. KMART #1 – Install in-system storage facility to attenuate and treat surface runoff from KMART roof and parking area that currently discharges directly to the stream. (Goal – Reduce frequency of damaging 2-year peak flow event, treat runoff prior to discharge, improve base flow condition, improve thermal conditions.)

2a. Bangor Mall #1 – As a result of **table 4.X** results, modify the existing Bangor Mall detention basin outlets to attenuate a 1-year storm event, decrease the discharge during a 2-year storm event, and permit a slightly higher discharge during 10- and 25-year events for a 66-acre contributing impervious area. (Goal – Reduce frequency of damaging 2-year peak flow events.) See section 4.4.2.

2b. Bangor Mall #2 – Modify the inflow entering the Bangor Mall detention basins to permit bypass of low flow, cool, clear underdrain discharges to enter the stream directly, instead of mixing with the warmer runoff contained in the wet pond for a 66-acre contributing impervious area. (Goal – Promote or restore stream base flow conditions, improve thermal conditions).

3. MDOT #1 – Install underdrained grass swales (bioretention swales) within the invert of the existing I-95 drainage swales to reduce frequency of damaging 2-year peak flow events, filter runoff through underdrain soil media, and promote stream base flow and improved thermal conditions for approximately 20 acres of contributing impervious area. (Goal – Treat direct runoff, promote or restore stream base flow conditions, improve thermal conditions).

4. EMCC #1 – Modify the existing EMCC detention basin by modifying the existing outlet structure weir to detain a 1-year runoff and installing a new small diameter outlet to drain off the storage over an extended period, and cooling the discharge with an extended buried pipe run prior to discharge into the stream for a 15.5-acre contributing

impervious area. (Goal – Reduce frequency of damaging 2-year peak flow events, promote or restore stream base flow conditions, improve thermal conditions).

Zoning Recommendations

4.0 – BMP Retrofit Designs

4.1 – BMP/LID Improvements Matrix:

The Maine DEP has developed a design manual to assist in selecting and developing appropriate Best Management Practices for development in Maine. Included with the DEP's publication is a selection matrix to aid selection of different types of BMPs. This matrix was used as a starting point in this report and expanded to specifically include the Penjajawoc subwatersheds, and to indicate which BMPs would be appropriate for retrofit or new installation where required. See table 4.0 – BMP Retrofit Matrix, included at the end of this section.

4.2 – Basic Approaches to Retrofit:

Three basic approaches to retrofit existing BMPs were identified:

- Construct new Low Impact Development infiltration swales to filter, attenuate, and cool runoff that currently discharges directly.
- Modify existing wet ponds to promote infiltration and base flow, while cooling runoff prior to discharge to the stream.
- Intercept underdrain runoff prior to entering ponds to promote base flow.

4.3 – BMP Retrofit Sites:

Four areas were outlined as possible areas of BMP retrofit improvements. See figure A-4 Proposed BMP Retrofit Subareas in Appendix A for locations of BMP tributary watersheds. The four (4) BMPs/sites were chosen to obtain the maximum benefit for investment, and to address the stated project goals. It just so happens that the BMPs occur in land controlled by a diverse group of stakeholders including the state, city, and private landowners.

1. The area surrounding K-Mart and Best Buy is a large 35-acre developed area containing virtually no BMPs. The area constitutes development predating current stormwater regulations, so most runoff directly enters the stream untreated by way of a piped municipal stormwater system. With 26.8 acres being impervious, this area represents 0.6% of the total watershed and 4.3% of the developed middle reach section. Several stakeholders have expressed the desire for this area to obtain retrofit BMPs. Included are subwatersheds 1220, 1090, 1092, 1093, and 1094. (See figure A-3 in Appendix A.)
2. The Bangor Mall stormwater system dates to the late 1970s and was refitted in 1998 to the sliding scale TSS removal standard. However, the regulations have since been updated. This 66-acre development represents 1.1% of the total watershed and 7.5% of the developed section.

3. Interstate 95 contributes roughly 20 acres of impervious area to the modeled watershed. It contains no formal BMPs and is likely a contributor of non-point source contaminants due to vehicle traffic. The total proposed BMP area is 15.8 acres, which is 0.3% of the total watershed, and 2% of the middle reaches. It should be noted that more of Interstate 95 flows through the watersheds of the Penjajawoc's tributaries, but these were considered out of the study area and only the 20 acres flowing directly to the Penjajawoc Stream were considered. This area contains some or all of subwatersheds 600, 1010, 1710, 2300, 2514, and 2510.
4. Eastern Maine Community College recently constructed a wet pond to treat runoff to 80% TSS removals. Due to stormwater rule changes, the new system is already obsolete. As it is located in an urban impaired watershed, the College is required to have adequate facilities for its runoff. 55 acres contribute to the existing detention pond, 15.5 of which are impervious, representing 0.97% of the total watershed and 6.7% of the middle reach section.

These retrofit areas will collectively affect 172 acres. This amounts to 3% of the total watershed and 21% of the middle reach section.

4.4 – Four Proposed New or Retrofit BMPs:

4.4.1 – K-Mart Location:

K-Mart and its surrounding area including Best Buy, Applebee's, and several strip malls, currently contributes 71 cfs to the stream during a 1-year storm. This runoff enters the stream at the middle reaches just upstream of the Bangor Mall outlet.

Suggested Retrofit:

1. Install flow-splitters and two (2) in-system underground storage structure(s) to attenuate 1- and 2-year frequency runoff from roof and parking areas that currently discharge directly to the stream.

Retrofit Purpose:

- Reduce frequency of damaging 1- and 2-year peak flow events;
- Improve base flow condition; and
- Improve thermal conditions.

Analysis:

Unless a significant reconstruction occurred and re-oriented the entire parking layout with horizontally placed and underdrained-bioretention swales, it was determined that LID retrofit systems would be ineffective in capturing surface

runoff and that structural BMPs and/or proprietary systems would be more viable when tied into existing storm systems.¹¹ A leading proprietary stormwater system company indicated that proper treatment of stormwater from this site would require large numbers of pretreatment and treatment structures and would therefore be prohibitively expensive. It was therefore determined that peak flow attenuation should be the method explored using more traditional and easy to maintain buried tanks and piping.

Sizing for the tanks was arrived at by using the channel protection volume (1" runoff from paved areas) multiplied by the 23 acres impervious contributing area from subareas 1091, 1092, and part of 1093. This resulted in the need for approximately 2 acre-feet of storage.

$23 \text{ acres} * 43560 \text{ SF per acre} * 1''/12 * 0.95 = 79,316 \text{ CF} < - \text{Greater value}$
 $(23 \text{ acres} * 43560 \text{ SF per acre} * 1''/12 + 2 \text{ acres} * 43560 \text{ SF per acre} * 0.4''/12) * 0.80 = 69,115 \text{ CF}$

The City of Bangor has in the past installed pre-cast concrete structures to attenuate the city's combined sewer overflows. These structures proved to be very cost-effective, being cheap to design and install and successful at serving their purpose. It was therefore proposed to install a similar structure underneath the parking lot of K-Mart. Two (2) 10' high by 8' wide by 500' long sections of pre-cast concrete chambers would store up to 600,000 gallons.

The flow splitters were modeled to direct 100% of the 1 year frequency event into the storage tanks, with any exceeding event bypassing the tanks and discharging into the downstream piped system. The nearly 2 acre-feet of storage provided in these tanks results in nearly ten hours of extended detention, and a flow reduction of nearly 93% compared to existing conditions.

Sufficient grade change exists within this storm system (excess of twenty feet) to permit the adequate burial of the ten foot tall tank system. K-Mart's parking lot is at elevation 120' NGVD. The bottom of the tank should be at or near elevation 98' and thus the top will reach elevation 108'. This leaves approximately 10 feet of grade remaining to install any catch basins, underground utilities, gravel subbase, etc.

The flow splitter was modeled as follows:

- (1) Primary outlet culvert, 24" dia., invert elevation 97.0
- (1) Secondary outlet culvert, 48" diameter, invert elevation 99.0

The tank outlet was modeled as follows:

- (1) 6.5" orifice in concrete wall at elevation 98';
- (1) sharp creseted weir (top wall) at elevation 107.46'

¹¹ The MDEP will allow structural BMPs on a case-by-case basis.

All outlet devices drain into an existing 48"-diameter storm drain pipe.

TABLE 4.X IN-SYSTEM TANK OPTIONS

Predevelopment (CFS)	~10	
Current (no BMPs)	47.68	
All flows into tank	Outlets 1x	Outlets 2x
Pond 1x	37.53	33.05
Pond 2x	12.57	9.24*
Flow Splitters	Outlets 1x	Outlets 2x
Pond 1x	31.16	25.59
Pond 2x	23.88	24.90

***Note:**

This BMP may require the installation of additional stormwater pipe into the existing system in order to convey runoff into the tank.

4.4.2 – Bangor Mall Pond Outlet:

The Bangor Mall detention Basins were constructed in 1977-1978 during the original Mall construction and later modified in 1998 during a major renovation project. The original 1977 hydrologic analysis was conducted by Raymond Keyes Engineers. The original design targeted a 50-year event. Sediment buildup over twenty years and failure of the pond primary outlet structure (piping and washout of outlet culvert piping and bedding) prompted remedial activity in 1998. The repair consisted of replacement of the primary outlet pipe, installation of anti-seep collars, raising the berm height to accommodate a 100-year storm event, and restoring wet pond volume by removing built-up sediment from both wet ponds. Additional armoring (articulating concrete mats) was installed at several weir locations in the pond.

The Bangor Mall system is engineered in such a way so that very cold (~50 degree) groundwater is exiting the system into the detention pond continuously at a minimum rate of 25 gallons per minute. This groundwater would be beneficial to the stream if it were to enter directly.

Suggested Retrofit:

To modify the existing stormwater detention pond, the suggested BMP retrofit at this structure consists of the following:

1. As a result of **table 4.X** results, modify the existing detention basin outlets from 24" to 18" culverts to attenuate a 1-year storm event, decrease the

discharge during a 2-year storm event, and permit a slightly higher discharge during 10- and 25-year events.

2. Modify the inflow entering the detention basins to permit bypass of low flow, cool, clear underdrain discharges to enter the stream directly, instead of mixing with the warmer runoff contained in the wet pond.

Retrofit Purpose:

- Reduce frequency of damaging 2-year peak flow event;
- Treat runoff prior to discharge, improve base flow condition; and
- Improve thermal conditions.

Analysis:

Reduction of the Bangor Mall pond outlet culvert from 24" to 18" diameter appears to result in a 35% reduction in flow out of the pond during a 1-year event; however, total flow at the discharge point in the stream is projected to decrease by about 9%. It should also be noted that if the pond outlet culverts were reduced to two (2) 18" openings, the discharges for 1- and 2-year storm events would decrease but any larger (10- and 25-year) storm event would see an increase in discharge. As research has shown, this may not be damaging to the stream.

Reduction of the outlet culverts to diameters of 15" or 12" was not feasible because of excessive weir overtopping. Raising the overflow weir to maintain control during 10- and 25-year events resulted in pond storage elevations peaking at levels higher than is commonly acceptable in current engineering practice. Raising the berm height to accommodate additional storage was not feasible due to space and budgetary constraints.

Results of this suggested modification during peak flow events are shown in the following table:

TABLE 4.X – BANGOR MALL POND OUTLET RETROFIT

81.85' top of berm				
79.85' weir invert	1-YEAR	2-YEAR	10-YEAR	25-YEAR
existing inflow:	112.10	128.91	207.21	243.00
existing:				
2X 24" CULVERTS	77.91'	78.40'	80.14'	80.25'
combined outflow	47.47	52.00	121.01	172.31
primary	47.47	52.00	65.44	66.28
secondary	0.00	0.00	51.89	106.03
try:				
2X 18" CULVERTS	78.69'	79.28'	80.25'	80.31'
combined outflow	31.77	34.38	144.35	200.91

primary	31.77	34.38	38.24	38.46
secondary	0.00	0.00	106.11	162.45
try:				
2X 15" CULVERTS	79.16'	79.79'	80.28'	80.37'
combined outflow	23.89	25.66	169.62	254.68
primary	23.89	25.66	26.96	27.21
secondary	0.00	0.00	142.61	227.47
try:				
2X 12" CULVERTS	79.71'	80.07'	80.34'	80.40'
combined outflow	16.33	42.04	199.16	266.90
primary	16.33	16.93	17.33	17.47
secondary	0.00	25.11	181.78	249.42

Note: primary outflow is two (2) culverts; secondary outflow is a broad-crested overflow weir.

The main outflow outlet for the Bangor Mall storm/underdrain system is a 54" diameter corrugated pipe. It emits a constant outflow of groundwater. This flow rate was measured at 25 gallons per minute in August 2006. Cold groundwater base flow would be beneficial to the Penjajawoc Stream. It has therefore been proposed to retrofit this outflow pipe with a device that would reroute the groundwater but continue to pass any storm events into the retention basin. One proposed method would be to install a basket full of riprap at the outlet of the 54" pipe. This basket would be removable for easy cleaning and would have a drain at the bottom to bypass the groundwater directly into the stream instead of into the retention pond.

4.4.3 – Interstate 95:

Interstate 95 contributes 20 acres of impervious surface to the Penjajawoc Stream, directly. In order to filter the runoff, underdrained vegetated soil filters with stone check dams have been proposed.

Suggested Retrofit:

1. Install stone-check/underdrained ditches within the invert of the existing drainage swales to reduce frequency of damaging 1-year peak flow events and to treat runoff prior to entering the stream.

Retrofit Purpose:

- Treat direct runoff;
- Promote or restore stream base flow conditions; and
- Improve thermal conditions.

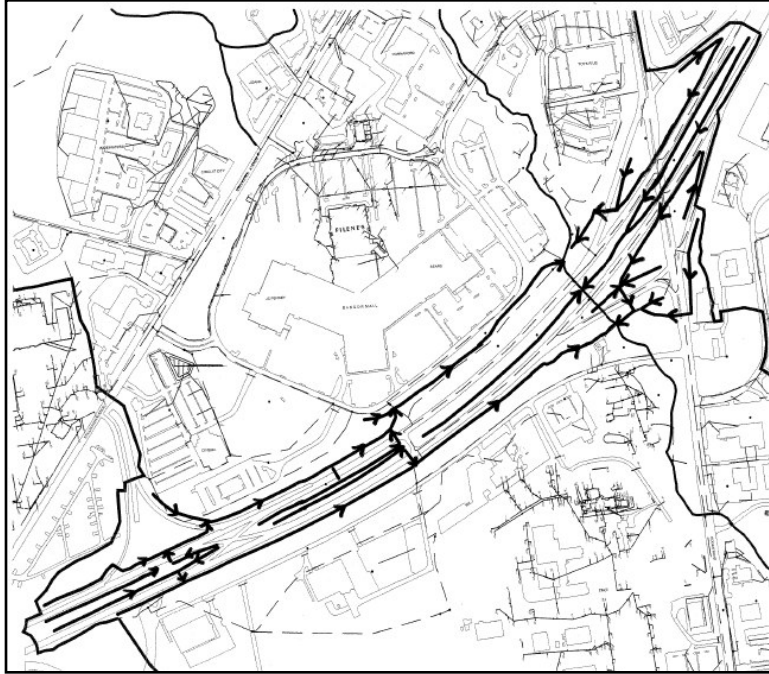
Existing and proposed outflow comparisons were not available for this site because the stormwater enters the stream at several different points.

Analysis:

It should be noted that the proposed BMP for this site is an innovation in BMP technology. It combines underdrained soil filter technology with check dams to produce a BMP with traits from both types of original BMPs.

The following is an image of some prominent flow paths taken by runoff from the Interstate. These were gauged by inspection of aerial photography and as-built plans provided by Maine Department of Transportation, dated 1978.

FIGURE 4.X FLOW PATHS FROM INTERSTATE RUNOFF



The following is a table of treatment volumes required for the freeway subcatchments.

TABLE 4.X BMP NEEDS OF FREEWAY SUBAREAS

WS	LF	SL	95% imp	80% all	Treatment vol. CF	Dams needed
600	1,500	3%	2,969	3,900	3,900	18
1010	2,000	3%	3,958	5,200	5,200	24
2514	4,000	2%	7,917	10,400	10,400	31
1710	4,000	2%	7,917	10,400	10,400	31

The stone check dams should be 18" high and retain an average of 9" of water. An infiltration rate of 0.08 cfs was assumed. The areas must drain in 36 hours or less. The length of the dam varies with local slope. Areas with a 3% slope receive dams that are 50 feet in length. Areas with a 2% slope receive dams that are 75 feet in length.

It was determined that the entire necessary length to treat the northern watersheds was not likely to fit into the space available. It was therefore determined that stone-check/underdrained soil filters should be placed where possible along the southern two subareas. An impermeable liner would not be necessary.

Treatment volume is defined as 1" times the impervious area plus 0.4" times the grassed area of a subcatchment. 95% of impervious area or 80% of all area must be included for treatment, whichever results in a greater treatment volume. It was assumed that each swale would be treating half the width of the roadway plus the shoulder of the roadway. The roadway is 50 feet wide, so on average each swale would be treating 25 feet of paved area per linear foot of roadway. The shoulder width was estimated to be 35 feet per linear foot of roadway.

Treatment volume for typical 50'-long roadway section:

$$25' \times 50' \times (1''/12) \times 0.95 = 99 \text{ CF}$$

$$(25' \times 50' \times (1''/12) + 35' \times 50' \times (0.4''/12)) \times 0.80 = 130 \text{ CF} < \text{Greater value}$$

Some soil filters drain in 72 hours. This may or may not be acceptable.

4.4.4 – Eastern Maine Community College:

The EMCC detention basins were constructed in 2004 to attenuate the runoff from post-1975 development and included capacity to attenuate runoff from more than two acres of future impervious development. The pond includes a permanent wet pond with storage above, and resulted in a weighted treatment for all Campus runoff of 80% TSS. The stormwater management rules were revised shortly after the construction of the wet pond.

Suggested Retrofit:

To modify the existing stormwater detention pond, the suggested BMP retrofit at this structure consists of the following:

1. Install a 6" storm drain with gate valve in the stormwater detention pond at invert elevation 85.35' so that the permanent wet pool elevation will be lowered from 87.35' to 85.35'. The outlet of the 6" storm drain will be connected to approximately 100' (171.5' effective length) of buried flexible corrugated perforated pipe (e.g. Hancor heavy duty pipe) to cool runoff before discharge into the stream.
2. Modify an existing control structure plate to attenuate below the 2-year event to a 1-year event:
 - Cover the three 5" orifices at elevation 87.35';
 - Narrow the length of the sharp-crested weir at elevation 88.35' from 4' to 2'; and

- Increase the rise of the sharp-crested weir from elevation 89.35' to elevation 91.55'.

Retrofit purpose:

All requirements for the college's stormwater effluent will be met with these improvements, resulting in a reduction of the 1-year peak flow from 13.53 cfs to 10.25 cfs.

Attenuating 90% of all storm events (1-year) and cooling the relatively warm wet pond will promote increased stream base flow and permit channel stabilization.

TABLE 4.X EXISTING AND PROPOSED SUBAREA OUTFLOWS (CFS)

(CFS)	1-YEAR	2-YEAR	10-YEAR	25-YEAR	100-YEAR	500-YEAR
existing inflow:	31.67	37.64	67.06	80.79	98.08	111.42
Existing pond total outflow	6.71	7.70	22.09	29.17	49.72	75.99
Proposed pond total outflow	5.42	7.90	20.32	26.87	35.29	55.37
Total outflow existing conditions	13.53	17.06	45.03	65.54	103.93	148.86
Total outflow proposed conditions	10.25	13.96	48.13	66.62	92.05	135.61

This retrofit results in a 20% decrease in pond outflow for a 1-year storm, and a 25% overall site decrease.

Analysis:

We are proposing to modify the stormwater detention pond to accommodate all of the post-1975 development that is located within the stormwater detention pond tributary area according to the revised DEP stormwater management rules.

TABLE 4.X IMPERVIOUS AND DEVELOPED AREAS IN THE STORMWATER DETENTION BASIN TRIBUTARY AREA ON THE EMCC CAMPUS (SF)

Sub-catchment	Pre-1975 (SF)			Post-1975 (SF)			Total (SF)
	Grass	Impervious	Woods	Grass	Impervious	Woods	
202	33,852	22,513	82,531	53,241	85,651		138,895
402	9,941		59,878	37,675	29,122	3,022	69,820
403	81,239	38,307	6,420	105,311	20,300	355	125,966
405	33,010		105,181	20,016	118,175		138,192
406	105,345		14,867	41,179	79,032		120,211
501	38,806	7,540	68,579	86,337	28,587		114,925
502	20,610	8,007	89,698	66,984	51,331		118,315

601	66,020	40,731	8,232	78,448	28,749	7,785	114,982
602	113,331	17,505	8,368	18,578	14,327	106,299	139,204
802	14,629	43,023	35,953	37,585	56,020		93,605
902	45,258	32,498	12,568	15,327	74,998		90,325
701A	16,005	66,800	10,147	412	92,540		92,952
Total (SF)	578,045	276,924	502,422	561,094	678,832	117,461	1,357,391
Total (acres)	13.27	6.36	11.53	12.88	15.58	2.70	31.16

Due to the pond's situation on a hillside slope, and due to the presence of adjacent stream and wetland vegetation, it is not feasible to further excavate the pond to provide room for a new underdrained filter bench around the perimeter of the pond.

Calculations:

a. Minimum Permanent Pool Volume

According to the revised DEP stormwater management rules, the minimum permanent pool volume equals 1.5" times the impervious area plus 0.6" times the non-impervious developed area:

$$1.5" \times (401,908 \text{ SF} + 49,132 \text{ SF}) + 0.6" \times 0 \text{ SF}$$

$$\underline{\text{Minimum Permanent Pool Volume}} = \underline{56,380 \text{ CF}}$$

b. Minimum Channel Protection Volume

According to the revised DEP stormwater management rules, the minimum channel protection volume equals 1.0" times the impervious area plus 0.4" times the non-impervious developed area:

$$1.0" \times (401,908 \text{ SF} + 49,132 \text{ SF}) + 0.4" \times 0 \text{ SF}$$

$$\underline{\text{Minimum Channel Protection Volume}} = \underline{37,587 \text{ CF}}$$

c. Existing Stormwater Detention Pond

Elevation at bottom of pond: 86.0'¹²

Elevation of permanent pool: 97.0'

Elevation at top of berm: 104.0'

TABLE 4.X EMCC STORMWATER DETENTION POND STORAGE VOLUME

Elevation (ft)	Surface (SF)	Storage (CF)
86.0	5,028	0
88.0	7,790	12,718
90.0	10,392	30,837

¹² Bangor City Datum

92.0	13,274	54,445
94.0	16,436	84,098
96.0	20,018	123,919
98.0	23,600	163,740
100.0	27,602	214,889
102.0	31,884	274,324
104.0	36,345	342,504

d. Proposed Stormwater Detention Pond Modifications

Install a 6" storm drain with gate valve in the stormwater detention pond at invert elevation 95.0' so that the permanent pool elevation will be lowered from 97.0' to 95.0'.

Permanent pool volume @ 95.0' = 104,009 CF > 56,380 CF -> OK

Provide the following modifications to the existing control structure plate:

- Cover the three 5" orifices at elevation = 97.0';
- Narrow the length of the sharp-crested weir at elevation 98.0' from 4' to 2'; and
- Increase the rise of the sharp-crested weir from elevation 99.0' to elevation 101.2.

Channel protection volume (95.0' to 98.0') = 59,731 CF > 37,587 CF -> OK

e. Minimum Treatment Percentage

Stormwater runoff from at least 95% of new impervious area must be treated:

- Post-1975 impervious area (detention pond): 401,908 SF
- Entrance drive impervious area (no treatment): 21,578 SF
- Impervious area treatment percentage:

$$(401,908 \text{ SF} / 423,486 \text{ SF}) \times 100 = 95\% \rightarrow \underline{\text{OK}}$$

Stormwater runoff from at least 80% of new non-impervious developed area must be treated:

- Post-1975 developed area (detention pond): 401,908 SF
- Entrance drive developed area (no treatment): 38,178 SF
- Developed area treatment percentage:

$$(401,908 \text{ SF} / 440,086 \text{ SF}) \times 100 = 91\% > 80\% \rightarrow \underline{\text{OK}}$$

f. Urban Impaired Stream Standard

The EMCC campus is located in a DEP-designated Urban Impaired Stream as defined in Chapter 502 of the Maine Department of Environmental Protection Rules. Therefore, the Urban Impaired Stream Standard applies to this project. We are proposing to treat a high use pre-development on-site parking lot to address this standard

Permitted Impervious Area (2001)

- a. Buildings: 158,743 SF (3.64 acres)
- b. Travelways: 481,589 SF (11.06 acres)

Proposed Master Plan

- a. Buildings: 234,393 SF (5.38 acres)
- b. Travelways: 538,553 SF (12.36 acres)

Required Credit

- a. Roof: $(0.2/\text{acre}) \times (5.38 \text{ acres} - 3.64 \text{ acres}) = 0.348$
- b. Non-roof impervious area: $(0.5/\text{acre}) \times 12.36 \text{ acres} - 11.06 \text{ acres} = 0.65$
- c. Total required credit: 0.998

Mitigation Credit

Treat pre-1975 high use parking lot with wet pond BMP (1.5/acre)

Parking lot behind Maine Hall: 49,132 SF

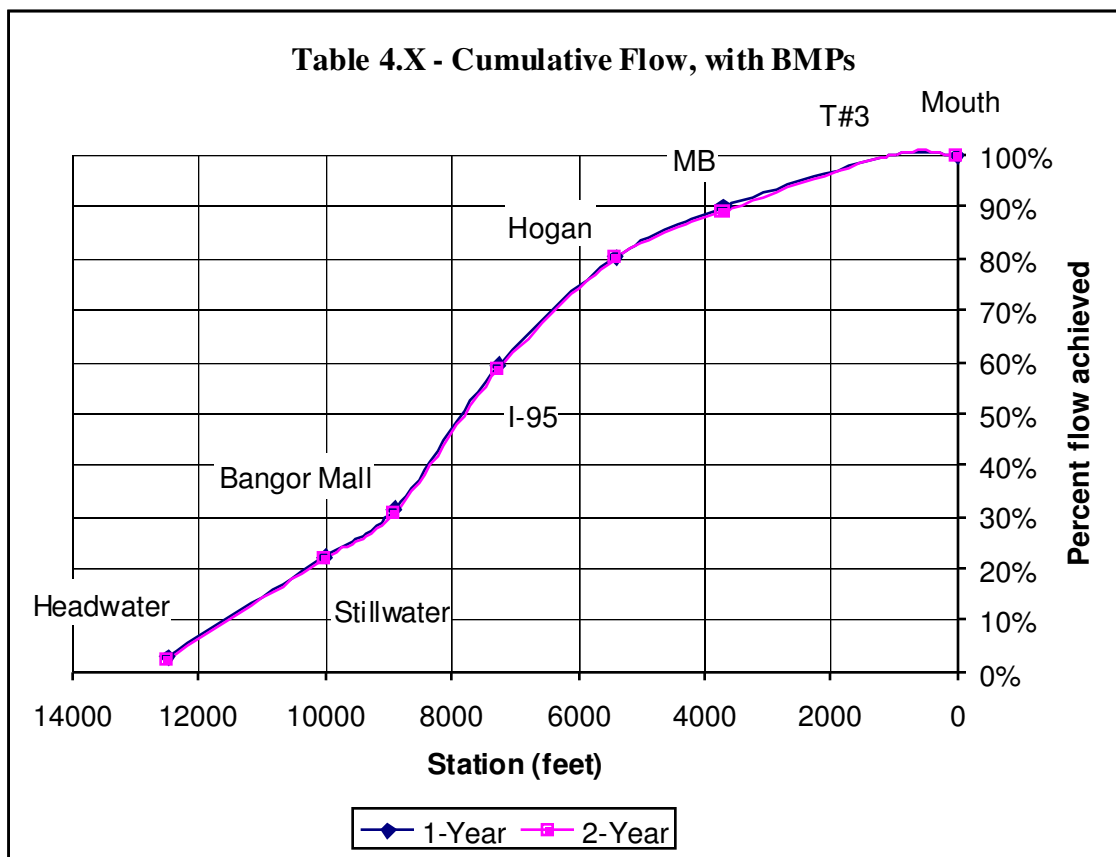
$$1.13 \text{ acres} \times 1.5/\text{acre} = 1.69 > 0.998 \rightarrow \underline{\text{OK}}$$

4.5 – Results of Hydrologic Model after Recommended BMP Changes:

After insertion of all four proposed BMPs, the hydrologic model was re-calibrated. The model gave the following resulting peak flows:

TABLE 4.X – FLOW AMOUNTS AT STATIONS (PROPOSED CONDITIONS)

STATION	PEAK FLOW (1-YEAR, CFS)	PEAK FLOW (2-YEAR, CFS)	DESCRIPTION
0+000	245.91	302.41	Mouth of Stream
0+950	246.43	303.07	Tributary #3 confluence.
3+700	221.16	269.41	Meadow Brook confluence
5+400	197.34	241.78	Hogan Road crossing
7+250	145.94	176.91	I-95 crossing
8+900	77.23	92.87	Bangor Mall Blvd crossing
10+000	54.84	66.45	Stillwater Ave crossing
12+500	7.00	7.00	Headwater (assigned)



4.6 – Zoning Change Recommendations:

Grandfathered private landowners need incentives to properly retrofit their stormwater systems. One suggestion would be to allow more development with the caveat that some funds would go toward mitigation. This tactic has been successfully implemented in many municipalities.

The concept of watershed-based zoning is one in which, in order to minimize the creation of additional impervious area at the regional scale, development is concentrated in high-density clusters. As Schueler and Holland state in their report, *The Importance of Imperviousness*, “Watershed-based zoning should provide managers with greater confidence that resource protection objectives can be met in future development. It also forces local governments to make hard choices about which streams will be fully protected and which will become at least partially degraded. Some environmentalists and regulators will be justifiably concerned about the streams whose quality is explicitly sacrificed under this scheme. However, the explicit stream quality decisions which are at the heart of watershed-based zoning are preferable to the uninformed and random ‘non-decisions’ that are made every day under the present zoning system.”

Again, we recommend the creation of a watershed manager position.

Innovative BMPs:

Stone-check/underdrained roadside ditch soil filter
Underdrained parking lot bioretention swale with overflow catch basin
Type ‘C’ underdrain in parking lot for simulating base flow
Crushed-stone-filled basket to catch low underdrain flows
End cap on large pipe to catch underdrain flows
In-system detention tank
Goals: manage runoff volume to reduce stream erosion
Wet retention basins = best performance
100’ of 4”-6” buried underdrain pipe serves to cool runoff

5.0 – Resources:

Contour information was obtained from city digital mapping data, record drawings provided by watershed stakeholders, and the Maine Office of GIS. Contours are at 10-foot intervals except where supplemented with archive data.

Information about the Hydrocad program's hydrology methods and practices was obtained from the program's Help files, and from the company web site, available at <<http://www.hydrocad.net/>>.

Information about existing projects such as Bangor Mall and EMCC was obtained from existing SLODA documents.

Water quality information was obtained from EPA-NE Maine water quality standards 1998 303(d) list, available at <<http://www.epa.gov/water/states/me.html>>.

References:

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- “Water Resources of Maine”, United States Geological Survey, United States Department of the Interior, <<http://me.water.usgs.gov/>>, (July 2006).

Appendix A – Supplemental Items and Appendices:

a. Figure A-1 Site Location Map:

1" = 1000' scale USGS map depicting overall watershed and location, watershed boundary, stream names, locations of existing or prior beaver activity, and existing BMPs.

b. Figure A-2 Stream Reach Identification:

1" = 500' scale map depicting site topography and stream stationing.

c. FIRM Maps:

Three (3) 11x17 color "FIRMETTE" maps; obtained from FEMA's Flood Insurance Study (FIS) program web site:

<<http://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1>>

d. Table A-1 Referenced Record Document List:

A list of all referenced record documents is included. Listed are scanned Adobe PDF documents obtained from Bangor City Hall, as well as documents from WBRC archives.

e. Figure A-3 Subwatershed Identification:

1" = 500' scale outlined subcatchment areas and numerical classification. See also eight (8) Sheets HY101-108 for 1:150 scale detailed subcatchment areas including Tc paths, reach paths (Tt), and pond locations.

f. Figure A-4 Proposed BMP Retrofit Subareas:

1" = 500' scale map of locations of proposed BMP retrofit improvement subareas.

g. Figure A-5 Soils:

1" = 500' scale map depicting soil types in the study area. See also four (4) USDA soil survey maps circa 1963, Penobscot County, # 222, 230, 231, & 239.

Appendix B – Hydrologic Modeling Results:

This report is intended to accompany and clarify hydrologic calculations compiled by WBRC Architects-Engineers for the Penjajawoc study area. Included in the following section is a description of methods and assumptions used in compiling said model.

Modeling Assumptions:

The stormwater runoff evaluation was developed in accordance with the methodology outlined and implemented within the “HYDROCAD” stormwater modeling system. The “HYDROCAD” modeling system was developed using techniques from the SCS TR-20 and TR-55. The 1-year, 2-year, 10-year, 25-year, 100-year, and 500-year; 24-hour, Type III storm events were used to calculate the peak rates of runoff for the watershed.

TABLE B1 – RAINFALL AMOUNTS

<u>EVENT</u>	<u>RAINFALL (INCHES)</u>
1	2.4
2	2.7
10	4.1
25	4.7
100	5.9
500	6.9

Based on the above “Methodology”, the following modeling assumptions were incorporated into the calculations:

- Per the Penobscot County Soil Survey of 1962, soils were classified according to Hydrologic Soil Group. Although the majority of soils were found to be Type C, all four types A, B, C, and D were found in the watershed. Distinction was made where possible; watersheds were not assumed to be all of one soil type as is commonly done in smaller projects. See Appendix A for figure A-5 for on-site soil types and USDA soil survey maps.
- The runoff curve numbers represented within the analysis identify the site characteristics for impervious areas, wooded areas, and grass cover. The following list represents the “Curve Numbers (CN)” used for this analysis:

TABLE B2 – CURVE NUMBERS

<u>CURVE NUMBER</u>	<u>DESCRIPTION</u>	<u>SOIL GROUP</u>
98	Paved parking lots, roofs, driveways, etc.	all
98	Paved; curbs and storm sewers	all
61	Good condition grass cover > 75%	B
74	Good condition grass cover > 75%	C
80	Good condition grass cover > 75%	D
69	Fair condition grass cover 50% to 75%	B
79	Fair condition grass cover 50% to 75%	C
84	Fair condition grass cover 50% to 75%	D
79	Poor condition grass cover < 50%	B
86	Poor condition grass cover < 50%	C
89	Poor condition grass cover < 50%	D
30	Woods, good	A
55	Woods, good	B
58	Woods/grass combination good	B
72	Woods/grass combination good	C
79	Woods/grass combination good	D
70	Brush, fair	C
77	Brush, fair	D

Weighted average Curve Numbers for individual watersheds ranged from 68 to 98.

- Typically, the time of concentration path within each watershed (subcatchment) was identified by sheet flow (300' maximum); shallow concentrated flow (paved, unpaved, grassed and wooded); pipes, and ditches and swales. The total vertical drop over the total segment length is how the slopes were calculated for each different segment. On the maps, time of concentration (Tc) segments are shown as bold dashed lines. Segment limits are defined by dots, and each segment is labeled with a length, a slope, and a flow type. Reach segments are shown as plain dashed lines; segment limits are defined by slashes and each segment is labeled with a length and slope. The referenced maps are included as Sheets HY101-108.

Time of concentration for individual watersheds ranged from 1.3 minutes to 70.4 minutes.

Onsite Watersheds:

The area of interest in the watershed was divided into 78 separate subcatchments, ranging from 9,300 square feet to 5,360,000 square feet. Impervious characteristics ranged from 1% to 100% imperviousness. (See figure A-3 Subwatershed Identification and HY101-108.) 818 acres out of 5,652 total acres were represented in the stormwater models. Watershed boundaries were obtained from MDEP and adjusted by WBRC where necessary due to local topography observations. A spreadsheet of detailed watershed ground cover is included at the end of this section as table B8.

Twelve (12) “HYDROCAD” files were used to model the area of interest, with five (5) additional models representing proposed conditions. The “HYDROCAD” calculations are included in this appendix. Several completed “HYDROCAD” files were obtained from contributing firms’ archives and/or Bangor City Hall project files.

Stream Modeling Methods and Assumptions:

The stream channel was modeled using 19 descriptive reaches. The stream was approximated as a trapezoidal channel; dimensions were available from field data provided by Parish Geomorph. Reach attributes are summarized in table B6 at the end of this section.

There are currently twelve (12) stream crossings. These include both culverts and bridges. See figure A-2 Stream Reach Identification in Appendix A for stream station attributes.

TABLE B3 – STREAM CROSSING LOCATIONS

CROSSING #	STATION	DESCRIPTION
1	0+000	Railroad
2	0+198	Route 2 - State St.
3	3+165	Mt. Hope Ave.
4	3+838	Evergreen Woods
5	5+245	BFCU
6	5+400	Hogan Road
7	6+222	New Sylvan Rd.
8	6+566	Old Sylvan Rd.
9	7+005	I-95
10	8+919	Bangor Mall Blvd.
11	10+111	Stillwater Ave.
12	12+171	Private drive

Due to the complexities of land coverage, marsh storage effects, beaver dam activity, and large wooded areas, the upper Penjajawoc watershed, Meadow Brook tributary and Tributary #3, were not modeled and were instead each input as an assigned 2-year base flow value. These values were obtained from the companion reports, but were not based on actual logged stream values. We suggest that these values be contrived for future watershed management activity. A value of 7 cfs (cubic feet per second) was used for the base flow contribution from Penjajawoc Marsh, entering the uppermost reach of the model. Calculated from data included in the Parish report, this number matched a value provided by ENSR in the SWMM study. Both tributaries were estimated to contribute 4 cfs. These estimates were intended to represent a dry season, such as August to September.

It was determined by use of the “upland” method that the peak time for the three large tributary subareas would lag the peak time of the developed area by between 5 and 10 hours. It was therefore determined that a base flow would be a more accurate

representation for the purposes of this analysis. Actual stream conditions may include groundwater contributions and exfiltration. These were assumed to be accounted for in the assigned base flow.

Runoff rates for the 1 yr., 2 yr., 10 yr., 25 yr., 100 yr. and 500 yr., Type III, 24-hour storm events for the hydrologic models are summarized in a **table**. Peak flows generated by the model were checked against projected flows obtained from the FEMA Flood Insurance Study, dated March 4, 2002. Flow landmarks for the 2-year storm event were furnished by Parish Geomorphic.

TABLE B4 – PEAK FLOW COMPARISONS (EXISTING CONDITIONS)

<u>EVENT</u>	<u>MODEL PEAK (CFS)</u>	<u>LANDMARK PEAK (CFS)</u>	<u>VARIANCE (CFS)</u>	<u>%</u>
1	269.91	--*	--	--
2	325.11	237	88	37%
10	610.08	510	100	20%
25	764.99	--*	--	--
100	971.31	1015	44	4%
500	1195.32	1555	360	23%

TABLE B5 – PEAK FLOW COMPARISONS (PROPOSED CONDITIONS)

<u>EVENT</u>	<u>MODEL PEAK (CFS)</u>	<u>LANDMARK PEAK (CFS)</u>	<u>VARIANCE (CFS)</u>	<u>%</u>
1	245.91	--*	--	--
2	302.41	237	65	27%
10	632.13	510	122	24%
25	798.74	--*	--	--
100	1019.24	1015	4	0.4%
500	1243.17	1555	312	20%

* No data available

TABLE B6 – STREAM REACH GEOMETRY USED IN HYDROCAD MODEL

PARISH Reach	Reach #	Stations Start/End	Bottom width (ft)	Channel depth (ft)	L/R side slope (ft/ft)	Length (ft)	n	Inlet/Outlet invert (ft)	Slope (ft/ft)	Base Flow (cfs)	Flood depth (ft)
PS1	R0	0+102/0+198	12	5	2	96	0.05	9/8	0.0104	0	--
	R1	0+253/0+945	12	3.5	3.4/4.3	692	0.04	20/15	0.0072	4	--
PS2	R2	0+945/1+969	12	3.5	3.4/4.3	1024	0.04	32/20	0.0117	0	--
	R3	1+969/2+369	12	3.5	3.4/4.3	400	0.04	34/32	0.005	0	--
	R4	2+369/3+165	12	3.5	3.4/4.3	796	0.04	37/34	0.0038	0	--
	R5	3+213/3+838	12	3.5	3.4/4.3	625	0.04	40.03/39.30	0.0012	4	--
PS3	R6	3+887/4+809	12	3.5	3.4/4.3	922	0.04	45/41	0.0043	0	--
	R7	4+809/5+246	12	3.5	3.4/4.3	437	0.04	51/45	0.0137	0	--
	R8	5+315/5+400	19	5.5	3.5/3.1	85	0.04	53.75/53.25	0.0059	0	--
PS4	R9	5+509/6+222	19	5.5	3.5/3.1	713	0.04	62/55	0.0098	0	--
	R10	6+316/6+566	11	5.25	1.5/1.3	250	0.04	64/63	0.0004	0	--
	R11	6+665/7+005	11	5.25	1.5/1.3	340	0.04	69/68.75	0.0007	0	--
PS5	R13	7+420/8+188	19	5.5	3.5/3.1	768	0.04	72/70	0.0026	0	--
	R14	8+188/8+919	19	5.5	3.5/3.1	731	0.04	77/72	0.0068	0	--
PS6	R15	9+027/9+832	6	3	4.3/2.7	805	0.03	84/77	0.0087	0	--
	R15A	9+832/10+111	6	3	4.3/2.7	279	0.03	86/84	0.0072	0	--
PS7	R16A	10+196/10+888	6	3	4.3/2.7	692	0.03	95/88	0.0101	0	--
	R16	10+888/12+121	6	3	4.3/2.7	1233	0.03	99/95	0.0032	0	--
PS8	R17	12+171/13+755	6	3	4.3/2.7	1584	0.03	105/101	0.0025	7	--

Hydrocad Model Information:

TABLE B7 – NODE MATCHING

LINK #	GOES INTO:	FILE NAME	NODE TYPE	NODE #
<u>318200 bmp retrofit design.hcp</u>				
L2	R2	318200 ws 10-1900 combined.hcp	Subcat	100
L3	R3	318200 ws 10-1900 combined.hcp	Subcat	10
L4	R4	318200 ws 10-1900 combined.hcp	Pond	100-R
6L	P3	318200 ws 10-1900 combined.hcp	Subcat	11
L5	P4	318200 ws 10-1900 combined.hcp	Reach	300-R
1L	R6	318200 ws 10-1900 combined.hcp	Reach	320-R2
L7	R6	318200 ws 10-1900 combined.hcp	Subcat	200
L8	P5	318200 ws 10-1900 combined.hcp	Reach	200-R
L9	P6	318200 EMCC Master Plan (Future 2) All.hcp	Reach	21R
L10	R9	291010-POST_DEVELOPED darling honda.hcp	Reach	25R
2L	P7	318200 ws 10-1900 combined.hcp	Subcat	1300
L11	P8	318200 ws 10-1900 combined.hcp	Reach	1700-R
3L	P8	318200 ws 10-1900 combined.hcp	Subcat	400
4L	R11	318200 ws 10-1900 combined.hcp	Reach	600-R
L14B	P9	318200 wS 2900,2700,2510,2300,2100.hcp	Reach	0
L12	P9	318200 ws 10-1900 combined.hcp	Subcat	800
L13B	P9	318200 1000series.hcp	Reach	0
L13	R13	318200 1000series.hcp	Reach	1000-R
L14	R13	318200 bangor mall 2550.hcp	Reach	24R
L15	P10	318200 1200series,1400SERIES.hcp	Reach	1200-R
L17	R15	318200 1200series,1400SERIES.hcp	Reach	1200-R4
9L	P11	318200 1200series,1400SERIES.hcp	Reach	0
L16B	P11	318200 wS 2900,2700,2510,2300,2100.hcp	Reach	R0
L16	R16A	318200 wS 2900,2700,2510,2300,2100.hcp	Subcat	2900
5L	P12	318200 wS 2900,2700,2510,2300,2100.hcp	Subcat	2920
L19	P12	318200 ws 3100 JWSewall.hcp	Reach	R6
<u>318200 ws 3100 JWSewall.hcp</u>				
1L	R1B	318200 ws 3100 upstream.hcp	Pond	12
<u>318200 1200series,1400SERIES.hcp</u>				
8R	1297-P	target Gorrill-Palmer.hcp	Reach	8R
10R	1297-R	target Gorrill-Palmer.hcp	Reach	10R
POI4	1299-R	target Gorrill-Palmer.hcp	Subcat	4
POI55	1297-R2	target Gorrill-Palmer.hcp	Subcat	5

- <318200 ws 10-1900 combined.hcp> is a Hydrocad file containing watersheds 10, 11, 100, 110, 200, 300, 310, 311, 320, 321, 322, 400, 410, 411, 412, 520, 600, 800, 1300, 1500, 1700, 1710, 1711, 1712, and 1900, along with 10 reaches and 6 ponds, for a total of 41 nodes.

- <318200 wS 2900,2700,2510,2300,2100.hcp> is a Hydrocad file containing watersheds 2100, 2300, 2510, 2511, 2512, 2513, 2514, 2700, 2710, 2720, 2730, 2740, 2750, 2900, 2910, and 2920, along with 7 reaches and 4 ponds, for a total of 27 nodes.
- <318200 1000series.hcp> is a Hydrocad file containing watersheds 1000, 1010, 1030, 1040, 1090, 1091, 1092, 1093, 1220, some parts of watershed 1091 that were described with 6 nodes by CES, 6 reaches, and 7 ponds for a total of 28 nodes.
- <318200 EMCC Master Plan (Future 2) All.hcp> is a Hydrocad file that was modeled by WBRC for a different project. It was inserted into the area entitled watershed 500. This plan contains 70 nodes. Watershed 500 is also modeled in part by the file <291010-POST_DEVELOPED darling honda.hcp>. This file, also made previously by WBRC, is of Darling's Honda on Sylvan Rd. It contains 48 nodes.
- <318200 bangor mall 2550.hcp> is a Hydrocad file that was made in 1998 by WBRC. It is of the Bangor Mall, contained in watershed 2550. Added to this file for completeness' sake was watershed 2500. It contains a total of 83 nodes.
- <318200 ws 3100 JWSewall.hcp> is a file of an unbuilt development contained in watershed 3110. It was obtained from J.W. Sewall and the model was linked into the project. It contains 67 nodes.
- <318200 ws 3100 upstream.hcp> is a Hydrocad file containing watersheds 3130, 3140, 3150, 3160, and 3120. Watershed 3120 was modeled by CES. This file has a total of 42 nodes, mostly from CES. This project links into JW Sewall's model of the Widewaters development.
- <target Gorrill-Palmer.hcp> is a model of the Target development from Gorrill-Palmer. It contains 23 nodes and links into model <318200 1200series,1400SERIES.hcp>. Some parts of this model do not drain into the Penjajawoc watershed. These outflows were discarded and the areas were not tallied.
- <318200 1200series,1400SERIES.hcp> is a Hydrocad file containing watersheds 1200, 1210, 1230, 1240, 1270, 1280, 1290, 1291, 1293, 1294, 1296, 1297, 1298, 1299, 1410, 1410B, 1412, 1413, and 1420. Also contained are 22 reaches, 12 ponds, and 4 links. The links are attached to the model for Target, which is contained in watershed 1292. This model has a total of 58 nodes.
- <318200 bmp retrofit design.hcp> is the model of the main Penjajawoc stream channel. It contains 60 nodes. This model contains no subcatchments; all inflow is linked from separate project files.
- <318200 tree diagram.hcp> is a Hydrocad file full of dummy nodes that show in which order all the files should be run.

- <bmp retrofit design proposed with bmps.hcp> should be run to simulate proposed conditions. It is the same as the existing conditions model but has the proposed BMPs linked instead of existing conditions. It was made to compare side-by-side with the existing conditions model without having to frequently reroute nodes. Many unchanged subareas have not been altered. The four BMPs have been accounted for.
- <318200 1000series future proposed.hcp> is a model to represent proposed conditions at the K-Mart development site. Reach 1000-R links into Reach R13 in the proposed model.
- <318200 FREEWAY RETROFIT PROPOSED.hcp> is a model of runoff around the freeway. It replaces two links. Its pond P8 links into Reach R10 in the proposed model.
- <EMCC Master Plan new.hcp> is a model that is the same as the existing-conditions model. However, the pond outlets have been modified to represent proposed conditions. Its outflow link is similar to the original model.
- <318200 bangor mall future proposed.hcp> is a model with different pond outlets than existing conditions. Its outflow link is similar to the original model.